Standard Operating Procedure and Workplan for the Terrestrial Environmental Observation Network (TEON) – Arctic Landscape Conservation Cooperative: Kuparuk River Basin and Adjacent Catchments

Spring breakup on Imnavait Creek, 2015

By

Emily K. Youcha, Robert E. Gieck, Christopher D. Arp, Sveta Stuefer, and Ken Irving

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TABLE OF CONTENTS

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CONVERSION FACTORS, UNITS, WATER QUALITY UNITS, VERTICAL AND HORIZONTAL DATUM, ABBREVIATIONS AND SYMBOLS

Conversion Factors

Multiply	By	To obtain
	Length	
inch (in.)	25.4	millimeter (mm)
inch (in.)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
acre	43560.0	square feet (ft^2)
acre	0.405	hectare (ha)
square foot (ft^2)	3.587e-8	square mile (mi^2)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
gallon (gal)	3.785	liter (L)
gallon (gal)	3785.412	milliliter (mL)
cubic foot (ft^3)	28.317	liter (L)
acre-ft	1233.482	cubic meter (m^3)
acre-ft	325851.43	gallon(gal)
gallon(gal)	0.1337	cubic feet (ft^3)
	Velocity and Discharge	
foot per day (ft/d)	0.3048	meter per day (m/d)
square foot per day (ft^2/d)	0.0929	square meter per day (m^2/d)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/sec)

Units

In this report, both metric (SI) and English units were employed. The choice of “primary” units employed depended on common reporting standards for a particular property or parameter measured. The approximate value in the “secondary” units may also be provided in parentheses. Thus, for instance, runoff was reported in cubic meters per second (m^3/s) followed by the cubic feet per second (ft^3/s) value in parentheses.

Physical and Chemical Water-Quality Units:

Temperature:

Water and air temperatures are given in degrees Celsius (°C) and in degrees Fahrenheit (°F). Degrees Celsius can be converted to degrees Fahrenheit by use of the following equation:

$$°F = 1.8(°C) + 32$$

Milligrams per liter (mg/L) or micrograms per liter (µg/L):

Milligrams per liter is a unit of measurement indicating the concentration of chemical constituents in solution as weight (milligrams) of solute per unit volume (liter) of water. One thousand micrograms per liter is equivalent to one milligram per liter. For concentrations less than 7000 mg/L, the numerical value is the same as for concentrations in parts per million (ppm).

Horizontal Datum:

The horizontal datum for all locations in this report is the World Geodetic System of 1984 (WGS84).

Vertical Datum:

“Sea level” in the following report refers to either the WGS84 datum (for approximate elevations of station locations). The datum for water level elevations is arbitrary.

Abbreviations, Acronyms, and Symbols

ADCP	acoustic doppler current profiler
ALCC	Arctic Landscape Conservation Cooperative
bgs	below ground surface
C	Celsius (°C)
cm	centimeter
d	day
F	Fahrenheit (°F)
ft	feet
GPS	Global Positioning System
GOES	Geostationary Operational Environmental Satellite
in.	inch
INE	Institute of Northern Engineering
km	kilometers
m	meter
mg/L	milligrams per liter, equivalent to ppm
mi	mile
mm	millimeter
NGVD	National Geodetic Vertical Datum
NRCS	Natural Resources Conservation Service
NSF	National Science Foundation
P-T	Priestley-Taylor
QA	quality assurance
QC	quality control
s	second
SBAS	satellite based augmentation system
SWE	snow water equivalent
RTK	real-time kinematic
TEON	Terrestrial Environmental Observation Network
TFS	Toolik Field Station
UAF	University of Alaska Fairbanks
USGS	U.S. Geological Survey
W	watt
WAAS	Wide Area Augmentation System
WERC	Water and Environmental Research Center
WGS	World Geodetic System
WWW	World Wide Web

1 INTRODUCTION

Increasing interest surrounds the Arctic hydrologic system and its response to climate change due to a suite of complex and poorly understood feedbacks (Serreze et al., 2003, Francis et al., 2009). Global climate simulations and limited observational data suggest hydrologic intensification, but this is highly uncertain due to the sparse measurements of terrestrial water balance (Rawlins et al., 2010). Simultaneously, existing circumpolar hydrologic observations are being reduced further with the discontinuation of long-term stations (Shiklomanov et al., 2002, Bring and Destouni, 2009). As a consequence, our ability to detect trends in the rapidly changing Arctic climate and further understand the terrestrial systems will suffer strongly without the continuation of long-term hydrologic observatories (Bring and Destouni, 2011). In the Arctic, a robust program for monitoring runoff from large river systems is currently in place (McClelland et al., 2006), while studies of smaller watersheds have tended to be more sporadic through time, thus limiting our ability to understand processes and detect changes at scales where the hydrologic cycle may be most sensitive to changes in evaporation and precipitation (Woo, 2012), runoff (McNamara et al., 1998; Kane et al., 2003), vegetation (Sturm et al., 2001), permafrost (Lachenbruch and Marshall,1986; Osterkamp and Romanovsky, 1999; Bowden et al., 2008), snow cover (Stuefer et al., 2013) or surface-water storage in the form of lakes and wetlands (Bowling et al., 2003; Arp et al., 2012).

Catchment and smaller basin streamflow records of varying duration have been maintained in U.S. Arctic for decades. For example, Brown et al. (1968) described the runoff processes of a 1.6 km^2 basin near Barrow over a four-year period beginning in the mid 1960's. In 1971, the USGS began collecting river gauging data at the mouth of the Kuparuk River, a mid-sized watershed draining an area of 8,140 km^2. This represents the longest continuous streamflow record in Arctic Alaska. In 1985, Kane et al. (2000) established a stream gauging station on the 2.2 km^2 Imnavait Creek watershed, complete with two weather stations capable of measuring meteorological inputs. The catalyst for this data collection program was the Department of Energy's R4D project at Imnavait Creek where the first meteorological data sites were established in 1985 and 1986. One year later in 1987, additional meteorological sites were established at Sagwon and Franklin Bluffs.

In 1992, another meteorological site was installed in conjunction with a wetlands study funded by the U.S. Geological Survey on the west side of the Prudhoe Bay oil field on the banks of the Kuparuk River. In 1993, the Imnavait Basin A site was moved several kilometers, renamed, and re-installed on the Kuparuk River south of the Dalton Highway near Toolik Lake. This effort was incorporated into a nested basin study with the addition of the Upper Kuparuk gauging station. Data from the Upper Kuparuk station, representing a watershed area of 143 km^2, was evaluated in conjunction with Imnavait Creek and the USGS Kuparuk outlet data along with complimentary meteorological data to produce Arctic Alaska's first nested-basin water balance results (Kane et al., 2000). Finally, in 1995, the first remote meteorological station that transmits via satellite was installed on the Kuparuk River 90 km south of the Arctic Coast in the western most part of the Kuparuk River Basin. In a parallel study, Kane et al. (2000) established a consistent gauging record on the Putuligayuk River (471 km^2) beginning in 1999, continuing monitoring done by the USGS from 1972 through 1995, thus capturing water balance data for a watershed confined to the low-gradient Arctic Coastal Plain (Bowling et al. 2003). In 2001, the U.S. Bureau of Land Management initiated stream gauging efforts in the National Petroleum Reserve – Alaska (NPR-A). In 2006, the Alaska Department of Transportation & Public Facilities (ADOT&PF), in conjunction with the Alaska Department of Natural Resources (ADNR), initiated river gauging studies in adjacent three coastal rivers. Concurrently, UAF initiated basin-scale water balance studies on the Anaktuvuk, Chandler, and Itkillik rivers in 2010. Studies of these river basins have already been completed however, as they were tied to development projects and never anticipated to continue long-term. The strength of the work in the Kuparuk River basin comes from its longevity, emphasis on understand hydrologic processes and simultaneous measurement of water balance components, and incorporation of graduate research and training of new Arctic hydrologists.

In Arctic landscapes, watershed processes are tightly linked to cold temperatures, permafrost, snow and glaciers, and strong seasonality in precipitation, storage, and runoff. Thus, a rapidly changing Arctic climate will affect watershed function and result in changes to the transport of water, sediment, and nutrients to downstream aquatic and marine ecosystems. There is increasing evidence of hydrologic intensification of the Arctic terrestrial water cycle, fueling inquiry into the hydrologic responses that integrate the varying climate and landscape units. Key to understanding these complex watershed processes is long-term hydrologic monitoring in Arctic Alaska. Accordingly, the Arctic Landscape Conservation Cooperative (ALCC) is initiating a Terrestrial Environmental Observation Network (TEON) to provide multiple stakeholders groups with environmental data needed to detect and forecast the effects of climate change on the physical environment, habitat, and wildlife.

The TEON plan proposes collection of a time series of specific environmental variables in seven representative watersheds across northern Alaska. The Kuparuk River watershed is central to this plan both because of its location that bisects Alaska's North Slope and its record of hydroclimatic data and research now surpassing 30 years. Nested catchments within and adjacent to this sentinel Arctic river system integrate climate and landscape responses from the Brooks Range foothills (Imnavait Creek and Upper Kuparuk River) to the Arctic Coastal Plain (Putuligayuk and Kuparuk rivers). This monitoring and research effort moves forward the critical initiation phase of TEON with surface water and meteorological observations in these watersheds and extends these observations to the crest of the Brooks Range with the inclusion of Roche Moutonnee Creek. The addition of Roche Moutonnee Creek not only completes this Arctic gradient, but also builds on historic streamflow records developed by the U.S. Geological Survey from 1976-1986 and current monitoring of flood peaks. Table 1 is a summary of meteorological stations installed for the Kuparuk and adjacent catchments for the TEON study.

Table 1. Summary of current meteorological stations in the UAF/WERC TEON network.

Station Name	**Station ID**	**Region**	**Basin Name**	**Elevation (m)**	**Coordinates**	**Period of Record**
Roche Moutonnee Basin	RMC-met	Mountains	Sagavanirktok	915	68° 22' 19" N 149° 16' 45" W	Jul 2015-present
Imnavait	IB	Foothills	Kuparuk	897	68° 36' 48" N 149° 19' 3" W	Aug/1986 - present
Imnavait Flume	IH	Foothills	Kuparuk	883	68°37'0.65"N 149°19'4.31"W	1985-present
Upper Kuparuk	UK	Foothills	Kuparuk	778	68° 38' 24.5" N 149° 24' 23.4" W	Aug/1993 - present
Upper Kuparuk River	UKH	Foothills	Kuparuk	741	68°38'34.06"N	1993-present

Station Name	Station ID	Region	Basin Name	Elevation (m)	Coordinates	Period of Record
					149°24'12.68" W	
Roche Moutonnee Creek	RMC	Mountains	Sagavanirktok	850	68° 22' 25" N 149° 18' 48" W	Jul/2015-present
Green Cabin Lake	GCL	Foothills	Kuparuk	908	68° 32' 01.0" N 149° 13' 47.4" W	May/1996-present
Franklin Bluffs	FB	Coastal Plain	Sagavanirktok	71	69° 53' 31.8" N 148° 46' 4.8" W	Aug/1986 - Present
Putuligayuk Basin	PBM	Coastal Plain	Putuligayuk	30	70° 05' 49.7"N 148°35'26.9"W	Jul/2015-present
Putuligayuk River	PR	Coastal Plain	Putuligayuk	9	70°16'3.03"N 148°37'48.48" W	Jun/1999 - present

The Kuparuk-TEON Project will extend Arctic environmental data in time and space, providing key datasets for analysis of climate, water and energy balance, and interactions with permafrost and vegetation. University of Alaska Fairbanks (UAF) through the Water and Environmental Research Center (WERC), along with Toolik Long-term Ecological Research (LTER, National Science Foundation) Station, has built and maintained meteorological and hydrologic observation network since 1985, and is thus well suited to continue it within the TEON framework.

The goal of this project is to install, operate, and maintain hydroclimate observation stations in the Kuparuk River basin and adjacent catchments (Putuligayuk River and Roche Moutonnee Creek) to obtain continuous data streams for TEON and the broader community of Arctic stakeholders. The project will collect and deliver specific meteorological and hydrological data that include streamflow, water temperature, precipitation, air temperature, relative humidity, radiation, and wind speed and direction. River gauges will be instrumented at catchment outlets, meteorological stations at central watershed locations, and end-of-winter snow surveys will be distributed throughout each catchment. Real-time data streams from these stations will be maintained to help ensure measurement continuity. The quality-controlled datasets will be provided to ALCC for public access and distribution annually together with metadata and documentation of standard operating procedures. Coordination with other efforts to monitor soils/permafrost and vegetation will be an important aspect of this project.

Major study objectives for this project are as follows:

Objective 1	Maintain and update instrumentation on existing river gauges and meteorological stations in the Upper Kuparuk, Imnavait Creek, and Putuligayuk River. Establish a new river gauge and meteorological station at Roche Moutonnee Creek. Ensure station operation and data quality at these stations over the project duration including sensor calibration.
Objective 2	Conduct spatially distributed end-of-winter snow surveys to estimate watershed-scale snow water equivalent (SWE) and spring ablation measurements to estimate timing and rate of snowmelt.
Objective 3	Conduct river discharge measurements at selected gauging sites in order to develop and/or update rating curves. Collect water level (stage) measurements at these locations and estimate the river hydrograph and water yield for the open-water season.
Objective 4	Monitor stream water temperature at an integrated location during flowing conditions for each watershed outlet.
Objective 5	Monitor river stage and catchment meteorology in real-time to ensure data collection continuity. Download, organize, and quality control station datasets (including water level, water temperature, streamflow, air temperature, relative humidity, incoming and outgoing (reflected) solar radiation, wind speed and direction, rainfall, and snow depth) and provide these to ALCC databases.
Objective 6	Conduct research and guide scientific training of students in TEON-Kuparuk catchments and using historic and current datasets. Foster collaboration and synergistic activities with other scientists in the study area.

2 STATION HISTORY

This section provides a brief history of the UAF/WERC sites in the Kuparuk River basin hydrologic studies beginning in 1985. Several of the stations/sites have been removed or discontinued, and several have been taken over by the TEON project.

In the Imnavait Watershed there are two main sites where data collection has taken place. One site, Imnavait A site is located on a 10% west-facing slope, the other site, Imnavait B site is located on a ridge top on the east side of Imnavait Creek Watershed. Meteorologic and soil information were measured at both locations. Near Imnavait A site four runoff plots were constructed in a transect along the slope. These sites were named Imnavait D site (plot 1, upper slope), Imnavait E site (plot 2, upper mid-slope), Imnavait F site (plot 3, lower mid-slope) and Imnavait G site (plot 4, lower slope). Snow and soil temperature profiles were measured adjacent to each runoff plot. Heat flux and precipitation were also measured at Imnavait C site, located midway between Imnavait F and G sites. Imnavait H site was established near the outlet of the basin to measure stream flow. Imnavait W site, otherwise known as the USDA Soil Conservation Service Toolik River Site, is a Wyoming snow gage located near Imnavait B site. Imnavait S site was established as a snow survey transect paralleling the slope next to Imnavait sites D, E, F and G (runoff plots) and running from the east boundary across the watershed to the west boundary. The soil physical properties at Imnavait basin were determined for hydraulic conductivity, bulk density, porosity and thermal conductivity at various depths and soil moisture conditions (Hinzman et al., 1991).

The mineral soils in this area (Imnavait) are cold, wet, poorly drained silt loams with a high organic content and include many glacial erratics of various sizes. The mineral soils are covered by a peaty layer, and are classified as Histic Pergelic Cryaquepts (Rieger et al., 1979). The vegetation is mostly water tolerant plants such as tussock sedges and mosses, but there are also lichens and shrubs such as willows, alder and dwarf birch. More complete descriptions of tundra vegetation have been published (Brown and Berg, 1980; Walker et al., 1989). The area was glaciated during the Pleistocene and is underlain by continuous permafrost. The maximum thaw depth during the period of study was approximately 120 cm, with typical depths being 40 cm.

In 1986, a second site was established near the Sagwon Bluffs approximately 100 km south of Prudhoe Bay. This site is located in a transitional zone between coastal plain and the foothills at an elevation of 370 m. The vegetation is also characteristic of tussock tundra and the soils are loamy with a peaty surface layer and are poorly drained (Everett, 1980). Instrumentation for measuring soil temperatures and meteorologic conditions as installed near the top of a 10%

north-facing slope. Data were collected for 25 years (1987-2011) at this site, the station was completely removed in 2011.

Also in 1986, a site near Franklin Bluffs was established on the coastal plain 50 km south of Prudhoe Bay. This site is located in the relatively flat area of the Sagavanirktok River flood plain at an elevation of 80 m. The vegetation is comprised of a continuous cover of grasses and sedges rooted in mosses and lichens (Komarkova and Webber, 1980). The soils are poorly drained and generally do not thaw to depths of more than 50 cm. Organic materials of variable thickness overlie silt-loam textured mineral soils (Everett, 1980). Data have been collected for 29 years (1987-present) at this site. This station will be continued through the TEON study.

The northernmost site was established 21 km west of Deadhorse on the banks of the Kuparuk River. This site is located in an area with little topographic relief at an elevation of 50 m. The vegetation consists of wet sedge tundra and forb tundra. The soils are organic overlying layers of fine sand and silts. This site was established in April of 1992. This station was taken down in 1995 and relocated to Betty Pingo, 1.4 miles (2.3 km) to the east, and Betty Pingo was operated until 2011.

Campbell Scientific 21X, CR10 and CR10X data loggers were used to record and process data at all sites. In 2009, a CR1000 was added to Franklin Bluffs station. Newer loggers (CR1000) are to be installed beginning in 2015 at the stations to replace the old CR10x models. Data recorded on the data loggers were compared to measured conditions to check the sensor calibrations and the data logger during site visits. Cables connecting the sensors to the data logger were shielded to minimize induced voltage caused by auroral activity. Heavy flexible metal conduit was used at some sites to discourage wildlife. Tripod masts (3 m) were used to mount sensors at Imnavait A site, Sagwon and Franklin Bluffs sites until 1995. In 1995, all existing stations were rebuilt and upgraded with 10 meter meteorological tower to mount the air temperature, relative humidity, wind speed and direction sensors. Radiation sensors were mounted on a separate tripod mount design to suspend this sensor over the tundra and minimize shadows. Also in 1995, two new stations were installed using 10 m towers. One meteorological station was located in the middle Kuparuk basin (West Kuparuk) with a full radiation array and soil temperature sensors and a second meteorological station was installed near the Beaufort Sea coast (West Dock), without soil temperature and only measuring net radiation. The West Kuparuk and West Dock station operated until 2008.

The USGS station at Roche Moutonnee Creek (USGS 15904900 Atigun River Tributary near Pump Station 4) was established in 1976. Daily discharge data are available from 1976 through 1986. After 1986, the site was operated as a crest gauge only. Approximately 74 discharge measurements were made at this station by the USGS. UAF will be expanding on the data collection at this location by collecting frequent runoff measurements during breakup and several lower flow measurements in the summer months.

3 DATA COLLECTION METHODS

Figure 1 and 2 show a typical meteorological station in the network. The station measures air temperature, relative humidity, wind speed and direction, summer precipitation, radiation, and winter snow depth on an hourly basis. Some stations are enclosed by an electric fence to deter wildlife from damaging the equipment. The hydrologic stations also record continuous water levels and water temperatures; we use the former to estimate river discharge. Some stations may be equipped with cameras to record images of the river and weather conditions on an hourly basis. The data are transmitted via telemetry where data are downloaded to the project websites in “near real time”:

http://ine.uaf.edu/werc/projects/NorthSlope/currentconditions.html (old website)
http://ine.uaf.edu/werc/research/ (new website for TEON)

Additionally, individual measurements of discharge are collected at the hydrologic observation stations (Upper Kuparuk, Imnavait, Putuligayuk, and Roche Moutonnee) during the spring runoff event and periodically during summer visits. We attempt to make discharge measurements twice daily during break-up to measure daily minimum and peak flow, but only occasionally during the ice-free season.

Tables 2 through 6 summarize the sensors that are installed (or will be installed) at each station in the Kuparuk TEON observation network and the sensors specifications. This chapter further describes the methods of data collection and the sensor specifications.

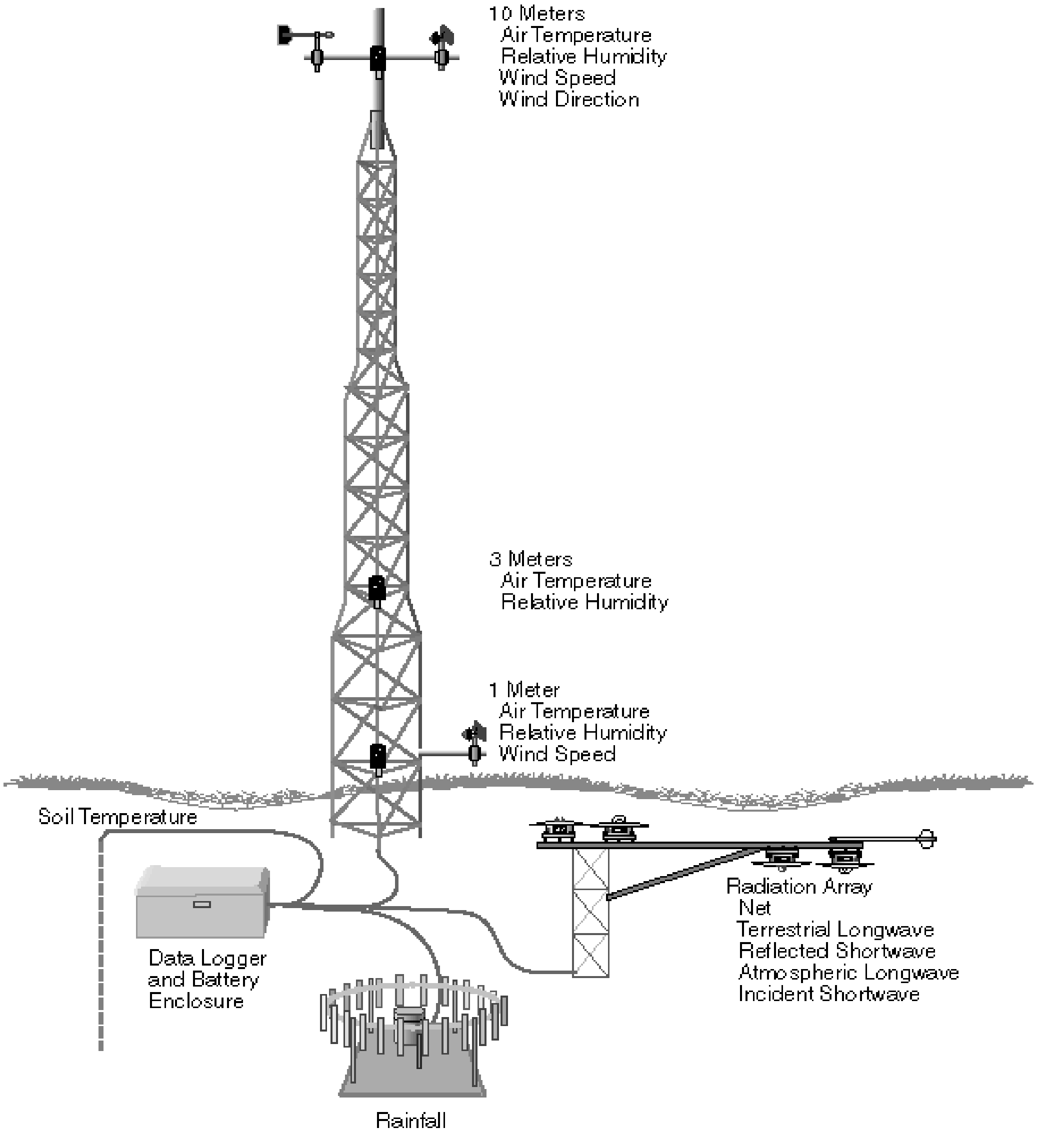

Figure 1. Typical 10 m tower meteorological station. Imnavait, Upper Kuparuk, and Franklin Bluffs are 10 m towers.

Figure 2. An example of a 3 m meteorological station. Putuligayuk Basin and Roche Moutonnee Creek stations will be on 3 m towers.

Table 2. Details of sensors and equipment at Upper Kuparuk and Imnavait meteorological stations. These stations have an existing 10 m tower and sensors are placed at 1 m, 3 m, and 10 m above ground surface.

Category	**Measurement**	**Sensor Model**	**Accuracy**
Met	Wind Direction, 10 m	RM Young 05103 or 05103-45	± 3 degrees
Met	Wind Speed, 10 m	RM Young 05103 or 05103-45	± 0.3 m/s
Met	Wind Speed, 3 m	Met One 014A	± 0.11 m/s
Met	Wind Speed, 1 m	Met One 014A	± 0.11 m/s
Met	Air Temperature, 1 m, 3 m, 10 m	HMP35C, HMP45C or H2CS3	± 0.5 °C at −40 °C
Met	Air Relative Humidity, 1 m, 3 m, 10 m	HMP35C, HMP45C or H2CS3	± 3 % at 20 °C
Met	Snow Depth	SR50 or SR50A	± 1 cm
Met	Barometric Pressure	CS106 Vaisala	± 1.5 mb @ −40 to +60 °C
Met	Net Radiation	Kipp and Zonen NR-Lite or NR-Lite2	
Met	Terrestrial and atmospheric longwave radiation	NR01 Hukseflux Pyrgeometer	Expected for daily totals: ± 10 %
Met	Incident and reflected shortwave radiation	NR01 Hukseflux Pyranometer	Expected for daily totals: ± 10 %
Met	Rainfall	Tipping Bucket TE525MM or TE525WS	± 1% up to 10 mm/hr (1 in/hr)
Soil	Soil Temperature	YSI 44033 thermistor	±0.1 °C
Station	Datalogger	CR1000	
Station	Radio/Modem	FreeWave FGR or DGR	
Station	Tripod	Existing 10 m tower	

Table 3. Details of sensors and equipment at new Putuligayak meteorological station. This station will have two 3 m towers.

Category	Measurement	Sensor Model	Accuracy
Met	Wind Direction, 3 m	RM Young 05103 or 05103-45	± 3 degrees
Met	Wind Speed, 3 m	RM Young 05103 or 05103-45	± 0.3 m/s
Met	Air Temperature, 2 m	HMP35C, HMP45C or H2CS3	± 0.5 °C at −40 °C
Met	Air Relative Humidity, 2 m	HMP35C, HMP45C or H2CS3	± 3 % at 20 °C
Met	Snow Depth	SR50 or SR50A	± 1 cm
Met	Barometric Pressure	CS106 Vaisala	± 1.5 mb @ −40 to +60 °C
Met	Net Radiation	Kipp and Zonen NR-Lite or NR-Lite2	
Met	Terrestrial and atmospheric longwave radiation	Eppley PIR Precision Infrared Pyrgeometer	
Met	Incident and reflected shortwave radiation	Eppley PSP Precision Spectral Pyranometer	
Met	Rainfall	Tipping Bucket TE525MM or TE525WS	± 1% up to 10 mm/hr (1 in/hr)
Station	Datalogger	CR1000	
Station	Radio/Modem	RAVENXTG cellular or equivalent	
Station	Tripod	Two CM110 3 m towers	

Table 4. Details of sensors and equipment at new Upper Roche Moutonnee and existing Green Cabin Lake meteorological stations.

Category	Measurement	Sensor Model	Accuracy
Met	Air Temperature, 2 m	HMP35C, HMP45C or H2CS3	± 0.5 °C at −40 °C
Met	Air Relative Humidity, 2 m	HMP35C, HMP45C or H2CS3	± 3 % at 20 °C
Met	Rainfall	Tipping Bucket TE525MM or TE525WS	± 1% up to 10 mm/hr (1 in/hr)
Station	Datalogger	CR1000 or CR10x	
Station	Radio/Modem	Iridium 9522B or FreeWave FGR/DGR	
Station	Tripod	One CM110 3 m tower or equivalent	

Table 5. Details of sensors and equipment at Upper Kuparuk River, Putuligayuk, and Roche Moutonnee gauging sites.

Category	Measurement	Sensor Model	Accuracy
Hydro	Water Level (two sensors)	INW AquiStar SDI-12, 5 psi	±0.05% Full Scale

Category	Measurement	Sensor Model	Accuracy
Hydro	Water Level	HOBO U20	±0.1% Full Scale
Hydro	Stream Temperature	INW AquiStar SDI-12, 5 psi	±0.5 °C
Met	Barometric Pressure	CS106 Vaisala	± 1.5 mb @ −40 to +60 °C
Station	Datalogger	CR1000 or CR10x	
Station	Radio/Modem	FreeWave FGR/DGR, RAVENXTG cellular or Iridium 9522B	

Table 6. Details of sensors and equipment at Imnavait Creek gauging site

Category	Measurement	Sensor Model	Accuracy
Hydro	Water Level (two sensors)	INW AquiStar SDI-12, 5 psi	±0.05% Full Scale
Hydro	Water Level	HOBO U20	±0.1% Full Scale
Hydro	Stream Temperature	INW AquiStar SDI-12, 5 psi	±0.5 °C
Met	Barometric Pressure	CS106 Vaisala	± 1.5 mb @ −40 to +60 °C
Met	Snow Depth	SR50 or SR50a	
Station	Datalogger	CR1000 or CR10x	
Station	Radio/Modem	FreeWave FGR/DGR	

3.1 Air Temperature and Relative Humidity

Air temperature and relative humidity were originally measured using a Campbell Scientific Model 207 Temperature and Relative Humidity Probe. The relative humidity component utilized a Phys-Chemical Research Corporation PCRC humidity transducer. These probes were housed in a self-aspirating radiation shield and are used to measure temperature and relative humidity at all sites. The reported temperature operating range is -33 to +48 degrees C with a worst case accuracy of plus/minus 0.4 degrees C and typically an accuracy of plus/minus 0.2 degrees C, and plus/minus 1 degree C from -33 degrees C to -40 degrees C. The relative humidity operating range is 12 to 100 percent with an accuracy of plus/minus 5 percent. A Campbell Scientific model 105T type T thermocouple was also used at the Imnavait B site. This thermocouple's calibrated range is -78 degrees to 50 degrees C, plus/minus 0.2 degrees C.

In 1995 HMP35C or HMP45C Temperature Relative Humidity Sensors were added to each main site at the 10 meter height. In 2000 the Model 207 Probe sensors were replaced with CSI Model 500 sensors. In 2004 all of the CSI Model 500 T/RH sensors were replaced due to corrosion problems in the sensor lead.

Now, air temperature and relative humidity are measured with a Campbell Scientific HMP35C or HMP45C Air Temperature Relative Humidity Sensor. These probes are housed in a 12-gill self-aspirating radiation shield and mounted at a height of 2 m. The reported temperature operating range is -40°C to +60°C, with accuracy typically ±0.3°C and a worst-case accuracy of ±0.5°C. The relative humidity operating range is 0–100%, with accuracy at 20°C of ±2% from 0–90% and ±3% from 90–100%. At some point, we may install the newer H2CS3 sensor (with similar specifications) because the HMP45C/HMP35C are now retired.

Rime ice accumulations can affect the air temperature and especially the relative humidity reading. Accumulating rime insulates the sensors within the radiation shield, isolating them from ambient conditions. Should this occur, air temperature readings would be slightly affected in the time required to respond to changes in the ambient air temperature, and relative humidity would be greatly affected by being isolated from ambient conditions. Recorded humidity is related to the vapor pressure of the surface of the rime ice adhering to the radiation shield and the wire mesh inner enclosure surrounding the relative humidity sensor, and is not indicative of actual ambient conditions.

Since the HMP45C sensor is not designed to give readings below -40°C/F and it is necessary to have backup sensors as well as multiple sensors for QA/QC, one or two YSI series 44033 thermistors were installed in a 6-gill radiation shield at a height of 2 m. The operating range of the three sensors is -80°C to +75°C (-112° to 167°F). These sensors are used if the temperature drops below -40°C/F or when the primary air temperature sensor (HMP45C) is malfunctioning.

3.2 Wind Speed and Direction

Wind speed was measured using a Weathertronics anemometer at Imnavait A site from 1985 through 1992. The threshold of the wind measurement is 0.22 m/s and the accuracy is plus/minus 0.07 m/s. Met One model 014A wind speed sensors were employed at Imnavait B site, Sagwon, Franklin Bluffs and Lower Kuparuk sites. The threshold velocity of this instrument is rated at 0.447 m/s and the reported accuracy is approximately 0.1 m/s. Beginning in 2006, all the 10 meter wind speed and direction sensors and most 3 meter sensors were replaced with RM Young 05103 anemometers.

Wind speed is typically measured using an RM Young 05103 anemometer, mounted at a height of 3 or 10 m. The starting threshold of the wind measurement is 1.0 m/s (2.2 mph), accuracy ±0.3 m/s (0.6 mph), and operating range of 0–60 m/s (0–134 mph). The wind-direction vane range is 0–360° with ±3° accuracy and a starting threshold at 10° displacement of 1.1 m/s (2.2 mph). Wind speed may also be measured with a MetOne 014 sensor with a starting threshold of 0.45 m/s (1 mph), accuracy of ±0.11 m/s (0.24 mph), and an operating range of 0.45-60 m/s (1-134 mph). Field calibration tests of the wind speed sensors are difficult to obtain. Suspect sensors are replaced and sent to the manufacturer for calibration and replacement of bearings. Additionally, the heading of the wind-direction sensors are checked periodically each year by pointing the vane at aiming points for four compass points. There are problems of note at these remote sites pertaining to wind speed and direction measurements. The most significant of these problems are rime ice and freezing precipitation that can alter the aerodynamics of the sensors and possibly stop them completely. Prolonged periods of calm and/or constant wind direction are rare at the stations and should not be considered in the data as indicators of these conditions. However, since the stations are unmanned, it is possible that a calm period could occur. Rime ice and freezing precipitation can occur during any season, but they occur most commonly during late fall, winter, and spring. Sensors are cleaned at each site visit, but due to the remoteness of the stations, visits are 6-12 months apart. Another problem, specific to the wind sensors, is perching birds. Since these sites are located in treeless tundra, large birds including ravens, rough-legged hawks, eagles, and snowy owls can damage vanes and anemometers by repeatedly perching on them. Perching rarely causes data loss but may slightly affect the accuracy of the wind vanes if they are bent or damaged.

3.3 Radiation

Radiation instruments are typically installed in the spring usually during March or April and taken down in the fall (late August or September). Since rime ice, snowfall and freezing precipitation can obscure the sensors in these instruments, values reported during periods of below freezing air temperature should be closely scrutinized. Reported radiation values during winter, early spring and fall should be considered qualitative and not quantitative. The following radiation components were measured: incoming and reflected shortwave radiation, atmospheric and terrestrial longwave radiation, photosynthetically active radiation and net radiation. Radiometer calibrations were checked locally each year by comparison to the output of an instrument of known precision. The Eppley radiometers are sent to Eppley Labs for reconditioning and recalibration as needed. All radiometers in use before 1988 were calibrated in March of 1989. Eppley radiometers were calibrated again in 1995 (estimated year) and 2015. All instruments are leveled at each site visit. Although the mounts were made as solid as possible, thawing and refreezing of the active layer soils above the permafrost did cause occasional shifting of the sensors between site visits.

3.3.1 Net Radiation

Net absorbed radiation was measured with a Swissteco model S-1 Net Radiometer at all sites from 1985/1986 through 1992. At the Lower Kuparuk site a REBS Q6 Net Radiometer was used. In 1993, all Swissteco net radiometers were replace with REBS Q6Net Radiometers. In 1998 all of the REBS Q6 net radiometers were upgraded to REBS Q7.1 net radiometers at all sites measuring net radiation. The operating range of the Swissteco instrument is 0.3 to 60 M; the accuracy is reported as plus/minus 2.5 percent. The Radiation and Energy Balance Systems (REBS) Q6 Net Radiometer's spectral response range is reported by the manufacturer as 0.25 to 60 uM, the calibrated accuracy of this instrument was not reported by the manufacturer. The

REBS Q7.1 radiometers have independently calibrated atmospheric and terrestrial sensors and measure the same spectrum.

Net radiation components, total hemispheric terrestrial and atmospheric radiation, were also measured using a Weathertronics Pyrradiometer at the Imnavait A site. This sensor produces two outputs, the total incoming and total emitted or reflected radiation, the difference being the net absorbed radiation. The accuracy of this instrument was reported to be within 2 percent.

Net radiation is also measured with a Kipp and Zonen NR-Lite Net Radiometer at the TEON stations, with the exception of Green Cabin Lake. The operating range of the Kipp and Zonen instrument is ±2000 W m^{-2}. The sensitivity is reported as 10 uV $W^{-1}m^2$. The spectral response range is reported by the manufacturer as 0 to 100 uM. Temperature range for the instrument is -30° to 70°C (-22° to 158°F). The calibrated accuracy of this instrument, which was not reported by the manufacturer, varies with temperature, wind, and sensor symmetry. Sensor readings are corrected for errors caused at high wind speeds. The instrument is installed at a height of approximately 2 m and oriented to the south to minimize shadow effect from the mounting pole. Keeping the sensor level is a challenge, especially at summer's end when the active layer thaw is at a maximum.

In 2015, the Hukseflux NR01 was installed at Upper Kuparuk and Imnavait stations to measure net radiation. The sensor consists of a pyranometer (short-wave) and a pyrgeometer (far-infrared) pair that faces upward and a complementary pair that faces downward. The pyranometer spectral response is 305-2800 nm and the pyrgeometer spectral response is 4500-50,000 nm. The operating temperature for the instrument is -40 to -80 °C. The expected accuracy for daily totals is ±10% and the sensitivity range is 10-40 uV $W^{-1}m^2$.

3.3.2 Shortwave Radiation

Incident and reflected shortwave radiation historically were measured with a Weathertronics Albedometer at Imnavait A site. The spectral range of this sensor is 0.3 to 3 microns, which excludes the terrestrial longwave component. The accuracy of this sensor is reported to be plus/minus 1 percent and the cosine response is less than 1 percent when the sun angle is within 0 to 70 degrees of perpendicular of the sensor plane.

Incident shortwave radiation was also measured using an Eppley model PSP Precision Spectral Pyranometer at Imnavait A site. This type of instrument was also used to measure incident and reflected shortwave radiation at Franklin Bluffs, Sagwon, and Lower Kuparuk sites. An Eppley Spectral Precision Pyranometer fitted with an RG8 dark red filter was used to measure photosynthetically active radiation between 0.700 and 2.800 microns at the Imnavait A site. This instrument has a reported spectral range of 0.285 to 2.800 microns, and a reported accuracy of plus/minus 1 percent in the range of values encountered. The cosine response of this instrument is plus/minus 1 percent between 0 and 70 degrees and plus/minus 3 percent between 70 degrees and 80 degrees zenith angle.

Eppley model 8-48 Black and White Pyranometers were used to measure incident and reflected solar radiation at the Imnavait B site. This instrument has a reported spectral range of 0.28 to 2.800 microns, and a reported accuracy of plus/minus 1.5 percent in the range of values encountered. Cosine response is reported as plus/minus 2 percent from normalization for angles of 0 degrees to 70 degrees and plus/minus 5 percent.

In 2015, the Hukseflux NR01 was added at Upper Kuparuk and Imnavait stations (specifications are listed above in 3.3.1 net radiation section). The Eppley PSP sensors were recalibrated, repaired and will be installed at the new Putuligayuk Basin meteorological station.

3.3.3 Longwave Radiation

Eppley model PIR Precision Infrared Pyrgeometers were used to measure longwave radiation, both terrestrial and atmospheric, at all sites. The spectral range of this type of instrument is 4 to 50 M, and the accuracy is reported as plus/minus 1 percent between 0 and 700 W/m2.

In 2015, the Hukseflux NR01 was added at Upper Kuparuk and Imnavait stations (specifications are listed above in 3.3.1 net radiation section). The Eppley PIR sensors were recalibrated, repaired and will be installed at the new Putuligayuk Basin meteorological station.

3.4 Summer Precipitation

Summer precipitation is recorded at each meteorological station with a Texas Electronics (TE) 525WS or 525MM tipping-bucket gauge surrounded by an Alter (wind) shield since the mid-2000s. The gauges catch precipitation in a 20.3 cm (8 in.) diameter collector (525WS) and 24.5 cm (9.66 in.) diameter collector (525MM), and the water is funneled into the tipping bucket. Once the bucket is full of water, it tips and empties, and each tip is recorded by the datalogger. The gauge is typically installed at a height off the ground of 0.7–1.0 m (2.3–3.3 ft). The resolution of the TE525WS tipping bucket gauge is 0.254 mm (0.01 in.), and the accuracy is 1% up to 25.4 mm/hr (1 in./hr), +0 to -3.0% for 25.4–50.8 mm/hr (1 to 2 in./hr) and +0 to -5% for 50.8–76.2 mm/hr (2 to 3 in./hr) rainfall rates. The TE525MM resolution is 0.1 mm per tip, and the accuracy is 1% up to 25.4 mm/hr, +0 to -2.5% for 25.4–50.8 mm/hr, and +0 to-3.5% (50.8–76.2 mm/hr), with greater undercatch as intensity increases; this does not include the impact of wind or other environmental factors. A known problem with most precipitation gauges is the undercatch of precipitation. Undercatch may occur during low-intensity or trace rainfalls (not enough precipitation to tip the bucket, and evaporation occurs) or high-wind events during which the gauge alters the path of rain particles. Undercatch may also occur due to interception and evaporative losses from the gauge surfaces. We recognize that this is a potential source of error, particularly for hydrological analysis and modeling of runoff. An additional potential error is due to the installation of the gauge. Rain gauges are checked at each visit to verify that the orifice is level as permafrost soils can heave or subside.

3.5 Snow Depth

Imnaviat flume, Upper Kuparuk, Franklin Bluffs, Putuligayuk Basin stations are equipped with a sonic snow depth sensor. The snow depth sensor type is a Campbell Scientific Sonic Ranger

SR50 or SR50(A). The only difference between the SR50 and the SR50(A) is the housing that encases the ultrasonic sensor. The sensor emits a 50 kHz sound pulse and measures the time the pulse takes to return to the sensor. Ultrasonic sensors can measure the distance to any reflective surface, like the ground or water, but sensitivity of the SR50(A) is designed for measuring distance to a snow surface.

The method for measuring snow depth with the SR50 is simple subtraction. When there is no snow on the ground, the distance measured is the sensor's height above the ground. When snow has accumulated under the sensor, the distance measured is to the snow surface. The difference between distance-to-ground and distance-to-snow is used to calculate snow depth. For example, if the sensor height above the ground is 100 cm and the new distance to surface is 90 cm, then subtracting 90 cm from 100 cm gives a snow depth of 10 cm under the sensor.

It is important to understand the problems of measuring and processing any observational data. Particular to ultrasonic snow-depth sensors is high-frequency small-amplitude noise, which is inherent in this technology and can be an impediment to accurate snow-accumulation measurements in real time (Brazenec, 2005). For example, since the speed of sound in air is affected by the air temperature it is traveling in, an air temperature measurement is required to correct distance readings. Additionally, sensor-mounting height can influence data quality, with higher mounting heights resulting in noisier data. Inaccuracies also can be caused by poor calibration and/or environmental weathering of the sensor. Physically related errors include high wind, falling snow, low-density snow, blowing snow, difficulty in establishing a zero point due to tussocks, low shrubs, grass, etc., and changes in sensor height due to ground heave and wildlife curiosity. Diligent field practices are essential for accurate measurements and for post-processing data correction and QA/QC purposes.

Field procedures include:

- Measuring the distance from the bottom of the sensor to the ground
- Measuring snow depth under the sensor
- Measuring the sensor to snow surface

- Conducting snow surveys near the station (50 snow depths and 5 densities/snow water equivalent)
- Inspecting the sensor and supporting structure for proper leveling and structural soundness
- Inspecting the sensor for corrosion and ice accumulation

3.6 Field Snow Survey

Our snow surveys include gravimetric snow water equivalent (SWE) sampling and snow depth measurements collected over an area of 25 m by 25 m; this technique is often referred to as *double sampling*. The snowpack in Alaska is extremely heterogeneous, with snow depth more variable than density (Benson and Sturm, 1993). Usually, double sampling yields an areal SWE estimate with a lower variance than is possible using collected snow cores only. Rovansek et al. (1993) showed that double sampling provides improved SWE estimates; they recommended sampling 12 to 15 snow depths for each snow core. This optimal ratio of snow depths to water equivalent, however, appears to vary greatly (from 1 to 23), depending on site, weather, and snow conditions. Currently, we use an optimal ratio of 10; that is, 50 depths accompany 5 snow cores.

Snow cores are sampled using a fiberglass tube ("Adirondack") with an inside area of 35.7 cm^2, equipped with metal teeth on the lower end to cut through dense layers of snow. The advantage of the Adirondack for shallow snowpack is that its diameter is larger than many other types of snow tubes (like the Mt. Rose); thus, it provides a larger sample of the shallow Arctic snowpack. To obtain a complete snow core, the Adirondack tube is pushed vertically through the snow while turning, until soil is encountered. At this point, snow depth is recorded. The tube is then driven further into the organic layer and tipped sideways, retaining a vegetation plug; this method ensures that the complete snow column was sampled. The vegetation plug is removed and the snow is either collected for weighing later in the laboratory or weighed in the field.

We use constant 50 m lengths for the snow depth course, with a 1 m sampling interval along an L-shaped transect. Twenty-five depth measurements are made on each leg of the L; this strategy is used to account for the presence of snowdrifts in the area of measurement. The directions of measurement are chosen randomly. Snow depth measurements are made using a T-shaped graduated rod (T-probe). The probe is simply pushed through the snow to the snow-ground interface.

Snow water equivalent is defined as:

$$SWE = SD * (\rho_s / \rho_w) \tag{1}$$

where ρ_s is average snow density from the 5 snow core samples, ρ_w is water density, and *SD* is an average of 50 snow depths.

3.7 Water Levels

For the TEON study, water levels are recorded at Roche Moutonnee, Upper Kuparuk, Imnavait, and Putuligayuk River stations. These stations were previously monitored by UAF and USGS. UAF observed water levels and discharge at Upper Kuparuk beginning in 1994, Imnavait Creek in 1985, Putuligayuk in 1999. Note that USGS operated the Putuligayuk gauge from 1970 to 1995, with daily stage and discharge from 1970 to 1986). USGS has operated Roche Moutonnee Creek (USGS 15904900, also known as Atigun River Tributary near Pump Station 4) as a crest gauge since 1976 and UAF installed continuous water level recording sensors in 2015 at the USGS station. Station locations are selected based on whether discharge can be safely and accurately measured during flood events. Water level (also known as river stage) is measured continuously with water level records, pressure transducers, and discharge measurements are individual point measurements in time. Point measurements of water levels are also collected with traditional surveying equipment and staff gauges. A rating curve is developed to establish a relationship between the stage and the discharge in order to predict the discharge at a particular river stage site. In addition to quantitative measurements, hourly photographs from cameras at the stations help us to evaluate the water levels in the rivers, observe ice conditions during break-up, and monitor the weather for field logistics.

Originally, stage data was recorded by Leupold Steven's F1 water level recorders with 10 turn potentiometers slaved to the drum gear. Pressure transducers were added starting in the mid-1990's. Currently, water levels are measured with an Instrumentation Northwest, Inc., Aquistar PT12 (SDI12) pressure transducers at each station, and with one or two HOBO U20 or Global Water WL400 pressure transducers for backup. Measurements are made every 15 minutes, and an average water depth or pressure is reported. Water depth above the pressure transducer is reported by the datalogger and is converted into water level elevations (above an arbitrary vertical datum) during post-processing. Traditional level loop surveys may be conducted to tie the water surface and staff gauges to the temporary benchmarks if they are available (with a known elevation).

Manual water level measurements consist of staff gauge readings or "tape downs," which are measurements from the top of a reference point such as rebar to the water surface. The staff gauge and rebar are surveyed to the datum as well. These discrete measurements of water level are used to adjust the continuous pressure transducer data to the datum and for verification purposes.

Some stations may be equipped with cameras, located at the surface water station, that take an image every hour (or more frequently as needed) to capture the river stage and weather conditions. The photos are used during the field season to observe river stage and ice conditions, and to corroborate the pressure transducer data. If the pressure transducer is not working properly, we can review the photographs to qualitatively confirm the river stage.

Table 7 shows the accuracy specifications for the Aquistar, HOBO, and Global Water pressure transducers. Errors associated with the pressure transducer itself are generally less than 1 cm under ideal conditions. Additional errors associated with the pressure transducer unit may occur if the sensor does not have a secure installation and is moving in the water.

Table 7. Specifications for the pressure transducers used during the study.

Sensor	*Full Scale Range*	*Accuracy (typical)*	*Accuracy (typical)*	*Water Level Range*

Aquistar PT12	0-15 PSI Gauge	0.06% Full Scale	0.009 PSIG, 0.6 cm	0-10 m
Aquistar PT12	0-5 PSI Gauge	0.06% Full Scale	0.003 PSIG, 0.2 cm	0-3.5 m
HOBO U20	0-21 PSI Absolute	0.075% Full Scale	0.016 PSIA, 0.3 cm	0-4 m
Global Water WL400	0-15 ft gauge	0.1% Full Scale		0-15 ft

The largest errors with manually measuring water levels are generally (1) surveying and vertical datum issues (2) mistakes during manual measurements (i.e., reading staff gauges), and (3) faulty or moving pressure transducers. Staff gauges may be read incorrectly, but it also may be difficult to read the staff gauge because of wave action that may yield an error in the water level of up to plus or minus several centimeters. We recognize that movement of the temporary benchmarks and staff gauges may occur from frost heave, ice damage, etc. Multiple level loop surveys and the use of static differential GPS survey to compare the temporary benchmark elevations from year to year help pinpoint movement.

All water level measurements are affected by ice or snow in the channel, which displaces water. This is important to be aware of during spring break-up and the winter months, because during this time, the rating curve is not valid since the channel geometry can be altered significantly due to the presence of ice or snow. During spring break-up, we take discharge measurements as frequently as possible and do not rely solely on the rating curve to calculate continuous discharge. The shift in the control during ice-affected measurements is visible in the rating curve; when the stage and discharge are plotted, the points will fall consistently above the rating curve (stage is higher for the same discharge when affected by ice).

3.8 Discharge Measurements

Stage discharge relationships were developed at each gauged site (Appendix A). Stage data were observed from staff gauges, tape downs, or surveying. Discharge measurements made with Price AA (Gurley) and Pygmy cup type current meters, Montedoro Whitney electromagnetic current meters and Sontek Flowtracker Acoustic Doppler current meters using standard USGS stream cross section techniques to estimate stream discharge from the recorded stage data.
Beginning in 2009, a tethered Teledyne RDI Streampro acoustic dopper current profiler (ADCP) is used to measure discharge at the Upper Kuparuk and in 2010 at Putuligayuk Rivers during the

highest stages (typically during spring breakup). Table 8 summarizes the sensors used to measure streamflow.

Table 8. Details of sensors that are used for the measurement of streamflow in the TEON study.

Category	Measurement	Model
Hydro	Flow, ADCP handheld	Sontek Flowtracker ADV
Hydro	Flow, Current meter	Pygmy Meter
Hydro	Flow, Current meter	AA Meter
Hydro	Flow, Electromagnetic handheld	Hach 950
Hydro	Flow, ADCP	RDI StreamPro ADCP
Hydro	Flow, ADCP Software	WinRiver II
Hydro	Flow, ADCP GPS Reference	Novatel Smart-V1 or Hemisphere A325
Hydro	Flow, ADCP Trimaran	Oceanscience Riverboat
Hydro	Flow, Computer	Panasonic Toughbook CF19 or equivalent

Once enough discharge measurements are collected at a station, a stage-discharge relationship (rating curve) is developed to calculate the discharge for a range of stages. The stage is plotted against the discharge and a best-fit curve is fitted through the points (and represented by an equation) on both normal and logarithmic scales. We attempt to collect discharge measurements at many different river stages in order to have a good relationship at all river stages. Extrapolation for low and high flows is necessary due to the lack of measurements in these ranges of the curve. Caution is used in extrapolating the discharges at high stages due to changes in the control at high stage. Once the stage increases above the banks (over bankfull conditions) onto the floodplain, the channel geometry changes, and the stage-discharge relationship developed for the channel is no longer valid. Also, since the geometry of the channel controls the relationship we try to make the measurements in the same location each time. However, due to a dynamic river channel during break-up, it is not always possible to measure the same river location each time. Changes in water flow paths at low versus high stage, multiple channels during high stage, and ice in the channel make it problematic to measure discharge at exactly the same location each day. It is common to have a shifting control, and therefore many measurements need to be made, along with adjustments (shifts) to the rating curve.

These data are continually compared to the long-term record to determine if any shifts have occurred in the stage-discharge relationship over time. This is particularly critical in the streams with limited or no control structure. Imnavait Creek's weir controls the flow at all flow levels. The Upper Kuparuk River is controlled by the Alyeska Pipeline pad at high flows (bankfull and above). The lower flow stage discharge relationship has been adjusted over time as channel morphology changes due to the migration of pools and riffles. The Putuligayuk River has excellent control for high and moderate flows derived from the culverts beneath Spine Road just downstream of the stilling well structure. During very low flow conditions a small riffle emerges between the stilling well and culvert inlets. Therefore, the stage-discharge relationship has varied over time. Roche Moutonnee Creek has no control structure and will be monitored annually to determine if shifts occur in the stage-discharge relationship. See Appendix A for examples of the current stage-discharge relationships.

3.8.1 Acoustic Doppler Current Profiler

Discharge measurements are conducted at or near the station on each river using the ADCP technique during flood stages. Measurements are made by pulling a tethered trimaran slowly across the river along a transect. Typically at least four transects are made, and an average discharge is calculated from the multiple transects. At times of high flow, the transects may be in an oblique angle (diagonal and downstream direction) across the river. Whenever possible, two transects from the left to right bank and two transects from the right to left bank are made to calculate river discharge and determine any directional bias. When the coefficient of variation (standard deviation / mean) of the four measurements is less than 5%, an average is calculated. If the coefficient of variation is greater than 5%, additional transects/measurements are made.

Both ADCP bottom tracking and GPS options may be used to measure river velocity. If bottom tracking is used, a moving bed test is generally conducted in order to correct for a moving bed.

However, if a moving bed may be an issue, the GPS reference is used. The GPS used is a Novatel Smart V1-2US-L1. Typically, a base station is set up and a real-time kinematic (RTK) GPS is used, but satellite-based augmentation system (SBAS or WAAS) differential correction is also used and is considered acceptable (Wagner and Mueller, 2011). The horizontal position accuracy of the RTK is 0.2 m and 1.2 m when using SBAS/WAAS.

The biggest challenge associated with making a good quality ADCP discharge measurement is locating a single straight parabolic cross section of the river with steady and uniform flow. A bad measurement section usually results in poor data quality. This is primarily a problem during the spring flood when ice is present in the channels, when flows may be high and unsteady, and when the river consists of multiple channels.

Technical problems and limitations of the ADCP and associated equipment are other factors that degrade the quality of the measurement. Technical problems may include GPS problems, radio communication failures, and incorrect baud rates. Typical ADCP limitations include turbulent water, too much or too little sediment in the water column, or insufficient water depth for use of a particular ADCP. However, we believe that ADCP measurements are far superior to traditional current meter measurements because the number of ADCP velocity measurements through the cross section is so much greater than could be measured with a conventional current meter.

The following field procedures occur before the ADCP discharge measurement:

- ADCP diagnostic and quality tests
- Moving bed test
- Compass calibration for GPS
- Assessment/description of the river reach characteristics for suitability of ADCP measurement

The following are reviewed during both quality assurance and control of the data:

- Measurement reach characteristics
- ADCP configuration

- Review of each transect and set of velocity contours for bad/lost velocity data
- Determine percentage of flow that is measured vs. estimated
- Review moving bed test and adjust discharge as needed
- Assess GPS quality if GPS is used
- Check each transect for consistency (discharge, area, width, boat speed, water speed, flow direction, measurement duration, etc.)
- Check that the transect coefficient of variation for discharge is within 5%

3.8.2 Measurement Data Quality

After the measurement at a site is reviewed, a quality rating that is both qualitative and quantitative is assigned to that measurement. The quality rating is based on both the transect coefficient of variation (i.e., measurement repeatability) and the overall general quality of the measurement (such as the river reach characteristics, ADCP limitations, transect consistency, etc.). The quality rating given to each measurement is either excellent (2%), good (5%), fair (8%), or poor (10% or more). These quality ratings are carried over to the rating curve.

Errors in water level and discharge measurements propagate to the rating curve. We assign quality indicators to each measurement and use these during the rating curve development. The complex and dynamic nature of these river channels adds additional uncertainty to the rating curve. Changes in the discharge measurement location may occur due to changes in stage that result in river access problems (i.e., too shallow to drive a boat), braiding of the river channel, and even safety issues. The change in the measurement cross section is not ideal and results in more uncertainty (and shifts) in the rating curve; however, there is probably little measurable change in flow between the measurement sites (typically they are all within a kilometer of the station).

Shifts can be applied to the rating curve when there is a change in channel shape or a change in the control. Channel shape can change during spring break-up when the river is affected by ice or during periods of sediment aggradation and degradation. However, at this time we have not applied shifts to the rating curve because additional measurements are still needed to better define the curve.

Additional errors may occur during the extrapolation of the rating curve beyond the highest or lowest measured discharge. It is typical that none or few measurements occur at the highest flows (for either safety reasons or we are not present during the high flows), so we extend the rating curve to these higher stage discharges. However, the rating curve may not be extended too high without consideration of the river cross section and changing controls. As we collect additional measurements and a better understanding of the river geometry and behavior, our rating curve will likely improve.

4 STATION TELEMETRY

To confirm that the stations are operating properly in this remote region we will use a telemetry system to receive data downloads in "near real time". The raw data are typically transmitted on an hourly or daily basis and downloaded to the UAF servers in "near real time". Raw data (no quality control) are available for the UAF staff and public to view in "near real time" plots at the TEON website. This section summarizes the historical and current telemetry network for the sites in the TEON study.

Building on work done by independent researcher Dave Hughes on using unlicensed Freewave radios to collect data from Campbell Scientific dataloggers, WERC installed a line-of-sight radio network using Freewave spread spectrum radios in the unlicensed ISM band at the Caribou Poker Creek Research Watershed; another network supporting ATLAS project research stations on the Seward Penninsula near Nome; and on the North Slope starting in 2002.

In April 2002, a radio base station was set up at Toolik Field Station (TFS), just prior to the installation of fiber optic internet link at TFS, and a repeater was established on the east end of Slope Mountain, overlooking many research sites in the Upper Kuparuk and Imnavait Creek watersheds. Though the the link from TFS to Slope Mountain was not quite in line-of-sight, it did work marginally well. In July 2002, with support from NSF and SRI Inc, a StarBand satellite internet system was set up at the Sag River DOT camp, along with a radio base node (and a StarDot Netcam, still functioning), greatly improving the effectiveness of the network.

In order to expand the scope of the network, a repeater was deployed in late 2002 on the summit of Sagwon Hill, allowing a link back to Slope Mountain and connections to the Sagwon Hill and Franklin Bluffs met stations. A base station was deployed in Deadhorse with a dial-up internet connection, allowing connections to be established to many sites from either Toolik, Sag DOT, or Deadhorse, and so providing significant flexibility and redundancy for the network.

Some stations were still out of reach of WERC's radio network, notably the West Kuparuk met tower. The West Kuparuk site was monitored from 1995 to 2000 using NOAA meteorburst data download, then in 2000 a GOES satellite uplink station was put there to push data via geostationary satellite to the Wallops Island facility. Unlike the Freewave radio network, which is fully bidirectional, the GOES system moves data only in one direction, so adjustments or program changes cannot be made.

Additional repeater stations were added in 2006 on Slope Mountain (better sited to look north) and on a ridge in the Upper Kuparuk watershed and close to Galbraith Lake. In ensuing years repeaters were installed on Imnavait Mountain and Itigaknit mountain, in addition to others both east and west of the Kuparuk drainage, supporting various expanded research projects. With these repeaters, WERC's Freewave radio network could now reach the West Kuparuk station, and the GOES equipment was removed from there.

At its peak, the WERC Freewave radio networks supported connections to about 50 research data and repeater stations, with some 30 or more of those sites in the North Slope Network. The network is operated in point-to-point mode, meaning that a connection is established from a chosen base station to a data station, through 1 to 4 repeaters; data queries are made and data collected; then the connection is broken down. With up to four base stations (two at Toolik) available, four different sessions could be run simultaneously, allowing data to be pulled from many stations with only a few minutes of radio on-time, especially during the winter months when power from solar panels is limited.

The WERC North Slope Freewave Radio Network provides a practical means to gather data from very remote research sites at very low cost per data byte. The network depends on strategically located repeaters and base stations, but with those in place, new stations can be added very simply to the network. In addition to pulling data from research dataloggers, new programs or adjusments to running ones can be pushed out to those loggers when necessary. Also, it is possible and sometimes very useful to connect to the Internet from remote locations during field operations.

The Putuligayuk Basin Met and Putuligayuk River stations use cellular communication telemetry through AT&T. Iridium communications will be used for both the gauging and the meteorological stations in Roche Moutonnee basin due to the remote location. These two types of telemetry options involve a monthly service plan with a cellular and Iridium provider.

5 DATALOGGER PROGRAM

The datalogger program controls how each measurement is made for each sensor. Programs were rewritten and loaded to the stations in July 2015 because newer dataloggers (CR1000) were installed at most of the stations. The current datalogger programs for each station are available in Appendix B. Historical versions of the program are available at the following website locations:

http://ine.uaf.edu/werc/projects/NorthSlope/upper_kuparuk/uk_river/csi-program.txt
http://ine.uaf.edu/werc/projects/NorthSlope/upper_kuparuk/uk_met/csi-program.txt
http://ine.uaf.edu/werc/projects/NorthSlope/imnavait/met/csi-program.txt

http://ine.uaf.edu/werc/projects/NorthSlope/imnavait/flume/csi-program.txt

http://ine.uaf.edu/werc/projects/NorthSlope/upper_kuparuk/green_cab_lake/csi-program.txt

http://ine.uaf.edu/werc/projects/NorthSlope/coastal_plain/put/csi-program.txt

6 METADATA

The metadata for each station will be provided in a text file and available online for download with the quality controlled data. The metadata contains information and history about each station, or data collection point, and describes the data, such as: station or site name, where the data is collected (location information), data availability, the method of measurement, and equipment/sensor type, and any other pertinent notes about the data being collected. At a minimum, the station metadata will include:

1. Project Name
2. Contact Information
3. Funding Sources
4. Dataset Overview
5. Site/Station Information
    a. Location (geographic coordinates, elevation, site description)
    b. Data coverage (date of range)
    c. Instrument layout/Sensors installed and location (height, depth, etc.)
    d. Measurement frequency/logging frequency / Datalogger program
    e. Data file naming convention
    f. Data file format
    g. Website location for archival
6. Instrument Description
7. Data collection procedure
8. Derived Parameters and Mathematical Operations
9. Calibrations
10. Parameter Units and Conversions
11. Data Remarks (Preventative and corrective maintenance, data quality/flagging codes)

7 QUALITY CONTROL AND DATA PROCESSING

Data is received in raw format and this data is considered Level I data. Some data adjustments / conversions are applied in the datalogger (such as the conversion of resistance to temperature for temperature measurements with thermistors), but other measurements are adjusted in post processing (such as converting water depth to water level elevation). After the raw data (Level I) is reviewed, corrections may be applied, and the data is available for the public to download and use, this data is considered Level II data.

Quality control occurs in both near real time data acquisition and during post processing of raw data (Level I). Near real time data is reviewed frequently by project technicians, particularly in the spring and summer months when site visits occur. This type of review includes checks for consistency, reasonable values, outliers, and rates of change in the measurement variable. Additionally, station battery and solar panel voltage is monitored to ensure no data is lost due to power outages.

During post-processing of the Level I data, the data is again screened for problems. The screening involves identifying data gaps, outliers/thresholds, examining rates of changes in the data between timesteps, and adjusting or rejecting the missing or erroneous data. Statistics are derived for the variables and data is reviewed graphically by technicians for the purpose of identifying problems in the datasets. A review of the calculations in the datalogger (multipliers, offsets, etc.) is also performed. Data that has been adjusted or rejected is noted with a data qualifier (flag or code). A final screening in Aquarius Time Series software is performed to further identify any erroneous data.

Data are generally hourly or daily average values. However, some data such as stream flow and snow water equivalent are point values taken at varying time periods. Hourly average values represent the average conditions during the hour proceeding the given time. Daily average values represent average conditions for the given day beginning at one minute past midnight and ending at midnight. All dates and times are in Alaska Standard Time.

Routine onsite station maintenance occurs for many reasons:

- preventative maintenance such as calibration of sensors and field checks of instrument performance
- replacement of equipment due to equipment malfunctions or damage
- retiring a sensor because it is outdated, etc.

Some of the longer outages in the data sets are due to damage caused by wildlife. Bears have been attracted to the sites and caused severe damage. Moose and caribou have damaged cables with their hooves and by rubbing on the towers. Smaller wildlife, rodents and foxes, have also gnawed cables causing outages. The severity of the weather encountered at these sites has also taken its toll on the instrumentation. Lightning and prolonged extreme cold have damaged data loggers and batteries causing outages.

8 DATA REPORTING AND ARCHIVING

As discussed above, the data is reported to a website in near real time and is considered raw (Level I) data. The data is considered final after the quality review and is then posted to the website for public download. The data is typically posted annually, but may be occur more frequently.

The following website was used to post real time data from mid-2000's to 2014:
http://ine.uaf.edu/werc/projects/NorthSlope/currentconditions.html

The following website was used to archive data from 1985-2014:
http://ine.uaf.edu/werc/projects/NorthSlope/northslope.html

A new website is being developed for the TEON project to display the near real time and archived data and will be located at the following website:
http://ine.uaf.edu/werc/research/

The file and data formats used from 1985 – 2014 are discussed below. The same file and data formats will be used for new datasets to maintain consistency. Data are compiled and tabulated in annual data sets for each site. These data were further subdivided into data sets of various types: meteorological, radiation, soil temperature and heat flux, stream flow and snow surveys. The first two characters in the file name specify the station name, the next four characters identify the year of the record, the final letters describe the general type of data. The codes for the site names, year and data types are shown in Table 9. The files are in comma separated ASCII format. Some examples of file names are:

IB1987M.DAT 1987 Imnavait B site meteorological data
FB1990R.DAT 1990 Franklin Bluffs radiation data
IH1991Q.DAT 1991 Imnavait Creek stream flow

Each file begins with several lines identifying the site, year of record and general type of data within the data set. Following this, specific data columns are identified.

This historical general file format will also apply to the future TEON datasets for consistency. The exception is that the radiation data (often identified with an ‘r’ in the historical filename) will be included in the meteorological data file. See Table 9 for details of the different data types.

Table 9. Historical file identification formats.

ID	Site Name	Data Availability
BM	Betty Pingo	1994 - 2011
FB	Franklin Bluffs	1986 - present

GL	Green Cabin Lake	1996 - present
IA	Imnavait A Site	1985 - present
IB	Imnavait B Site	1986 - present
IC	Imnavait C Site	1985 - 1992
ID	Imnavait D Site	1985 - 1992
IE	Imnavait E Site	1985 - 1992
IF	Imnavait F Site	1985 - 1992
IG	Imnavait G Site	1985 - 1992
IH	Imnavait Flume	1986 - present
IS	Imnavait Snow Course	1985 - 1992
IR	Imnavait Ridge Site	1993 - present
IV	Imnavait Valley Site	1993 - present
IW	Imnavait Wyoming snow gage	1985 - 1992
LK	Lower Kuparuk Site	1992 - 1995
NH	North Headwater	1996 - 2010
SH	Sagwon Site	1986 - 2012
SW	Sagwon Wyoming snow gage	1986 - 2010
UH	Upper Headwater	1996 - 2010
UK	Upper Kuparuk Site	1993 - present
WD	West Dock	1995 - 2008
WH	West Headwater	1996 - 2010
WD	West Kuparuk Site	1995 - 2008

Table 9. Historical data types.

Data Types	
M	Meterological
Q	Stream Discharge
R	Radiation
S	Snow Surveys
T	Soil Temperatures (includes soil heat flux at Imnavait C)

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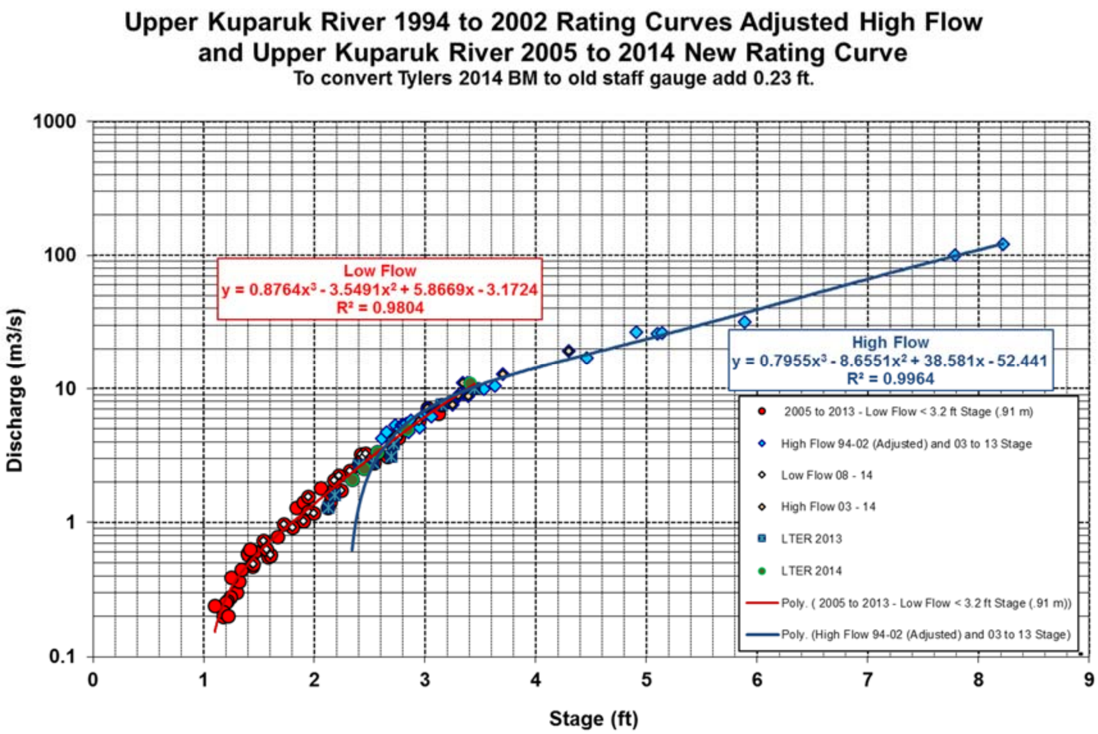
10 APPENDIX LIST

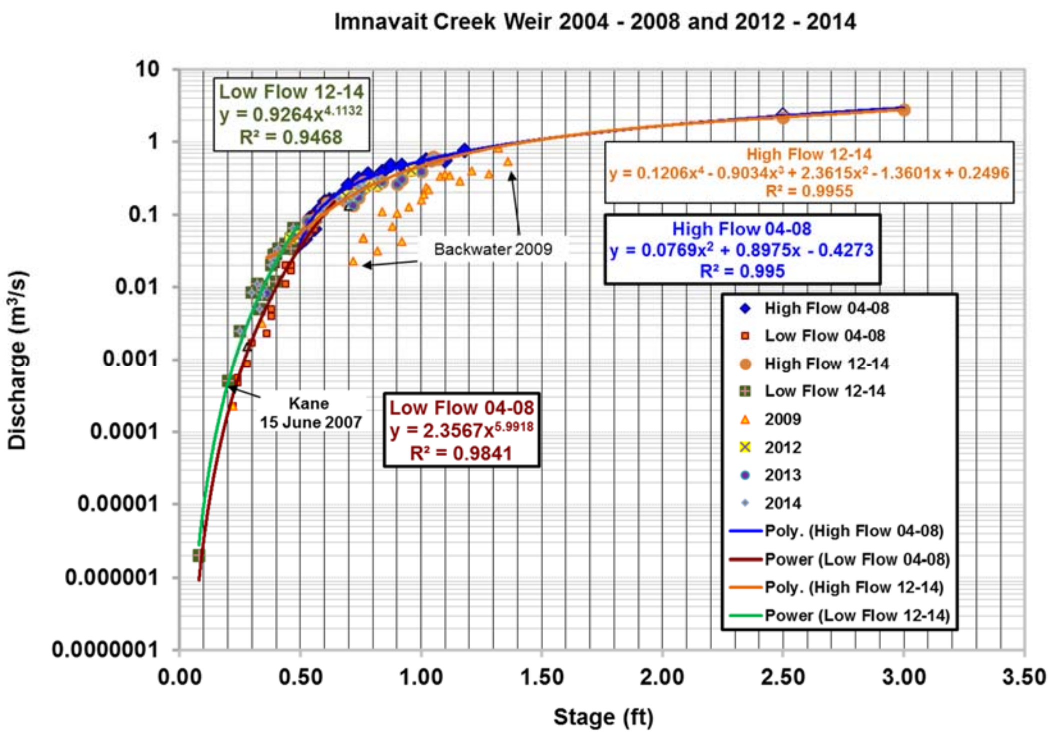
Appendix A: Rating Curves

Appendix B: Station Programs

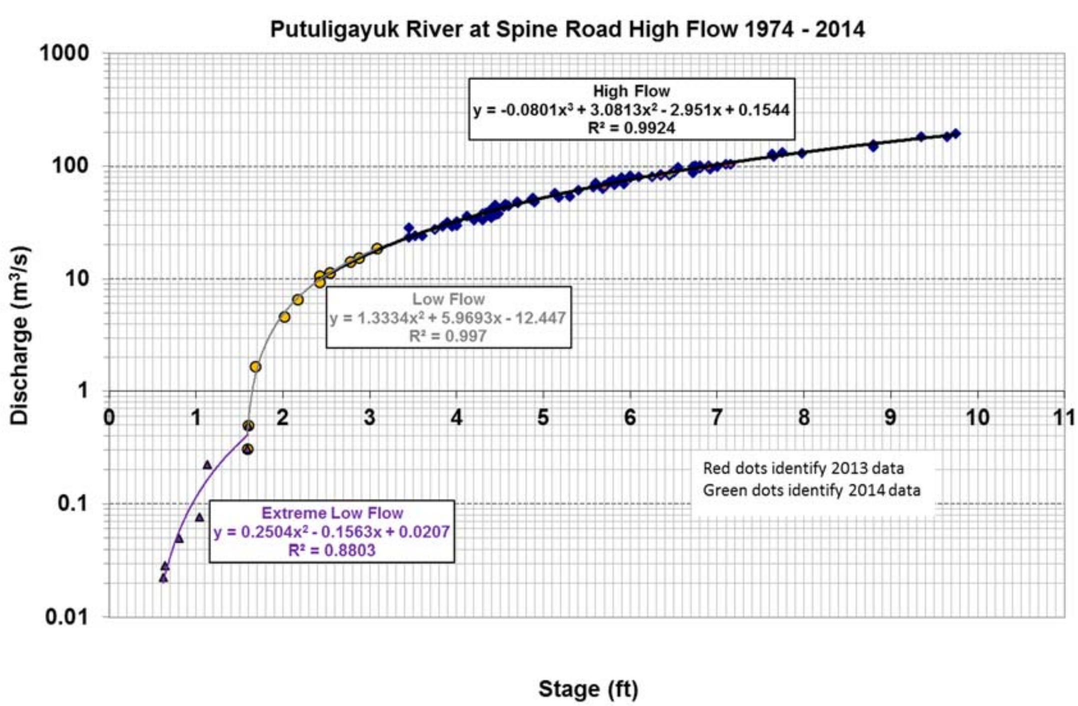
APPENDIX A

Rating Curves for Upper Kuparuk, Imnavait, and Putuligayuk Rivers.





Imnavait Creek Weir 2004 - 2008 and 2012 - 2014
Low Flow 12-14
y = 0.9264x^4.1132
R² = 0.9468
High Flow 12-14
y = 0.1206x⁴ - 0.9034x³ + 2.3615x² - 1.3601x + 0.2496
R² = 0.9955
High Flow 04-08
y = 0.0769x² + 0.8975x - 0.4273
R² = 0.995
Backwater 2009
Kane
15 June 2007
Low Flow 04-08
y = 2.3567x^5.9918
R² = 0.9841
High Flow 04-08
Low Flow 04-08
High Flow 12-14
Low Flow 12-14
2009
2012
2013
2014
Poly. (High Flow 04-08)
Power (Low Flow 04-08)
Poly. (High Flow 12-14)
Power (Low Flow 12-14)
Discharge (m³/s)
Stage (ft)



Putuligayuk River at Spine Road High Flow 1974 - 2014
High Flow
y = -0.0801x³ + 3.0813x² - 2.951x + 0.1544
R² = 0.9924
Low Flow
y = 1.3334x² + 5.9693x - 12.447
R² = 0.997
Extreme Low Flow
y = 0.2504x² - 0.1563x + 0.0207
R² = 0.8803
Red dots identify 2013 data
Green dots identify 2014 data
Discharge (m³/s)
Stage (ft)

APPENDIX B

Current datalogger programs for stations (last updated July 2015)